Novel method for the determination of unknown biomass fuel properties based on results of an online monitoring in a 300 kW CFB pilot plant

Daniel Bernhardt, Michael Beckmann

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**Fuel range**

- Small amounts (<10,000 t/a)
- Different sources
  → Variable fuel properties

**Power Plants**

- Design and operation is optimized on „regular fuel“

**Challenges**

Varying Flue gas emissions

Deposits/Corrosion vs. Availability/Costs

Flexible Biomass utilization needs biomass specific process optimization
Model-based process control

Identification of unknown fuel properties

Power Plant (e.g. CFBC)

Process data acquisition

Process analysis (Online-Balancing)

Monitoring (Sensors + Models)

Control Variables
Fuel, Air, Additives

New targets for control variables

Source: BEB Bioenergie Baden
Characterization of the feedstock material – Organic composition of natural biomass

- Cellulose, Hemicellulose & Lignin are main components ($\Sigma = 92$ wt.-% daf)

- Distribution varies in wide range

- No similarities within biomass groups

- Linear correlation between Hemicellulose & Cellulose
Characterization of the feedstock material – Fuel Properties of Organic material

Slide 4
Elemental-Mass-Balances
→ Assumptions: $\xi_{\text{Fuel},N} = \xi_{\text{Fuel},S} = 0$

\[
\xi_{BS,C} = \frac{\dot{m}_{AG,f}}{\dot{m}_{BS}} \cdot M_C \left( \frac{\xi_{AG,CO,f}}{M_{CO}} + \frac{\xi_{AG,CO_2,f}}{M_{CO_2}} \right) + \xi_{FA,C} \cdot \frac{\dot{m}_{FA}}{\dot{m}_{BS}}
\]

\[
\xi_{H,BS} + \xi_{H,O,BS} \cdot \frac{2 \cdot M_H}{M_{H_2O}} = 2 \cdot \frac{M_H}{M_{H_2O}} \left( \xi_{H,O,AG} \cdot \frac{\dot{m}_{AG,AG}}{\dot{m}_{BS}} - \xi_{RG,H_2O} \cdot \frac{\dot{m}_{RG,f}}{\dot{m}_{BS}} \right)
\]

\[
\xi_{BS,O} + \xi_{BS,H_2O} \cdot \frac{M_O}{M_{H_2O}} = \frac{\dot{m}_{AG,f}}{\dot{m}_{BS}} \left( \xi_{AG,O_2,f} + \xi_{H_2O,f,AG} \cdot \frac{M_O}{M_{H_2O}} \right) - \frac{\dot{m}_{RG,f}}{\dot{m}_{BS}} \left( \frac{\xi_{BS,H_2O}}{M_{O_2}} + \xi_{RG,H_2O} \cdot \frac{M_O}{M_{H_2O}} \right)
\]

Energy-Balance

\[
\dot{H}_{BS} + \dot{H}_{RG,PL} + \sum_{i=1}^{3} \dot{H}_{RG,SL,i} + \sum_{i=1}^{3} \dot{H}_{RG,S,i} = \dot{H}_{AG} + \dot{H}_{FA} + \dot{Q}_{KW} + \dot{Q}_{V}
\]

Additional Statistic

\[
\begin{align*}
\xi_{SC} & = 0.057087 \quad \xi_{SO} = 0.072748 \\
\xi_{SH} & = \text{cellulose/ hemicellulose} \\
\xi_{S0} & = \text{lignin} \\
\xi_{S2O} & \text{structural components}
\end{align*}
\]
Identification of Unknown Fuel Properties – Results Online-Balancing (C, H, O, H₂O)
# Identification of Unknown Fuel Properties – Structural Analysis

## Elemental composition and heating value of structural components

<table>
<thead>
<tr>
<th>Structural component</th>
<th>$\xi_C$ [wt. – %]</th>
<th>$\xi_H$ [wt. – %]</th>
<th>$\xi_O$ [wt. – %]</th>
<th>$\xi_N$ [wt. – %]</th>
<th>$\xi_S$ [wt. – %]</th>
<th>$h_u$ [MJ/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macro molecules</strong></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td><em>Cellulose (Cel)</em></td>
<td>44.4455</td>
<td>6.2165</td>
<td>49.3380</td>
<td>0.0000</td>
<td>0.0000</td>
<td>15.9758</td>
</tr>
<tr>
<td><em>C$<em>6$H$</em>{10}$O$_5$</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hemicellulose (HCel)</em></td>
<td>45.4556</td>
<td>6.1034</td>
<td>48.4410</td>
<td>0.0000</td>
<td>0.0000</td>
<td>16.3180</td>
</tr>
<tr>
<td><em>C$_5$H$_8$O$_4$</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><em>Lignin (Lig)</em></td>
<td>67.7639</td>
<td>5.6868</td>
<td>26.5493</td>
<td>0.0000</td>
<td>0.0000</td>
<td>26.0543</td>
</tr>
<tr>
<td><em>C$<em>{17}$H$</em>{17}$O$_5$</em></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Extractives (Amino Acids (AA) representing proteins)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>S-free AA (AA,S-free)</em></td>
<td>44.4756</td>
<td>7.3882</td>
<td>34.9393</td>
<td>13.1969</td>
<td>0.0000</td>
<td>19.4730</td>
</tr>
<tr>
<td><em>S-containing AA (AA,S-containing)</em></td>
<td>38.9555</td>
<td>7.2330</td>
<td>22.0557</td>
<td>9.6544</td>
<td>22.1014</td>
<td>20.8952</td>
</tr>
</tbody>
</table>

i...C, H, O, N, S
j...Structural component
Objective function

\[ F = \min \left\{ \sum_{i=C,H,O}^{O} \left( x_{fuel,OB,i} - \bar{x}_{fuel,i}^{*} \right)^{2} + \left( h_{u,fuel,OB} - h_{u,fuel}^{*} \right)^{2} \right\} \]

Constraints

\[ \xi_{Cel} + \xi_{H Cel} + \xi_{Lig} + \xi_{AS,S-frei} + \xi_{AS,S-haltig} = 1 \]

\[
\begin{align*}
12,20 & \leq \xi_{Cel} \leq 63,21 \\
6,57 & \leq \xi_{H Cel} \leq 64,55 \\
2,53 & \leq \xi_{Lig} \leq 44,08 \\
1,00 & \leq \xi_{Extr} \leq 25,60 \\
\end{align*}
\]

\[ \xi_{H Cel} = 64,41 - 0,8921 \cdot \xi_{Cel} \]
Identification of Unknown Fuel Properties – Results of Structural Analysis

The slide shows a stacked bar chart comparing calculated and measured structural compositions of different fuels including wood chips, grain residues, and switchgrass. The chart differentiates between cellulose, hemicellulose, lignin, and extractives.
Identification of Unknown Fuel Properties – Results of Structural Analysis

**Slide 11**

**Graph 1:**
- **Title:** wood chips
- **Data:**
  - mass fraction $\xi_{\text{fuel}}$ [wt.-%]
  - heating value $h_u$ [MJ/kg]

**Graph 2:**
- **Title:** grain residues
- **Data:**
  - mass fraction $\xi_{\text{fuel}}$ [wt.-%]
  - heating value $h_u$ [MJ/kg]

**Graph 3:**
- **Title:** switchgras
- **Data:**
  - mass fraction $\xi_{\text{fuel}}$ [wt.-%]
  - heating value $h_u$ [MJ/kg]

Legend:
- **Calculated** (green)
- **Measured** (orange)
- Presented method provides “Online” information about unknown fuel properties of biomasses:

  - Online Balancing: $\xi_C$, $\xi_H$, $\xi_O$, $\xi_{H2O}$ and $h_u$

  - Structural analysis: $\xi_{Cel}$, $\xi_{H Cel}$, $\xi_{Lig}$, $\xi_{Extr}$ and $\xi_N$, $\xi_S$

- Validation was realized for three biomasses with different compositions

- Method exemplarily developed for CFB combustion of biomass is transferable to other firing systems (e. g. grate systems)

- Deeper information about extractive composition would improve the accuracy of the method
Further work – novel process model for CFB combustion of biomass

**Process data**
- fuel (structural composition!)
- reaction gas
- temperature and pressure

**Simplified process model**
→ based on structural composition

**Forecast:**
- burn out
- emissions

**Process optimization**
- air distribution
- air preheating
- additives
Acknowledgement
Thank You for Your Interest!
(Riverfront of Dresden)